

AN OVERVIEW OF THE PLANKTONIC FORAMINIFERAL FAUNA IN WATERS OFF THE KERALA COAST, SOUTH-WEST INDIA DURING SUMMER

K. KAMESWARA RAO AND K.V. JAYALAKSHMY

National Institute of Oceanography, Regional Centre, Cochin-682 018, India

ABSTRACT

Twentyeight species of planktonic Foraminifera are recorded from 46 plankton samples collected from 27 stations of 5 traverses along the Kerala coast. The mean abundance of total foraminiferal specimens of all the stations in each traverse shows that it increases from south to north. Two distinct foraminiferal assemblages have been noted in the fauna: first is the summer tropical one typified by species such as *Globigerinella aequilateralis*, *Globigerinoides conglobatus*, *G. ruber* and *G. sacculifer*, while second one known as summer tropical upwelling assemblage is formed by species, viz. *Globigerina bulloides* and *Neogloboquadrina dutertrei*. The spinose species of the genus - *Globigerinoides* - are the most abundant.

A factor analysis of faunal data shows the grouping (Q-mode analysis) of foraminiferal species into (i) rare and (ii) dominant species, besides a few rare ones; this study indicates that dominant forms in the area can adapt to a wide range of environmental conditions. The same study with R-mode analysis for stations depicts that traverses 5 (0-10m) and 4 (0-200m) are distinct in showing the least faunal abundance. The fauna in general has a close affinity with that of waters in tropical and subtropical zones of the north Atlantic in summer.

INTRODUCTION

ALTHOUGH information available on Recent planktonic Foraminifera in the open Arabian Sea is satisfactory due to contributions of earlier authors, it is still inadequate from viewpoint of their distribution, seasonal study and ecology in the coastal waters of the Indian region (Rao *et al.* 1992). Therefore, these aspects of the fauna form a part of the work plan on extensive ecological studies of the waters of south-west coast of India. A study of planktonic Foraminifera off this coast in summer is of particular interest, since stable marine conditions prevail only during this period. A survey of this kind has a bearing on climatic changes in the atmosphere as they have their counterparts in the sea. Consequently, changes in the foraminiferal fauna of the waters in the sea from time to time generally reflect the climatic conditions.

We are grateful to Dr. E. Desa, Director, for his keen interest and support and to Dr. V.N. Sankaranarayanan, Scientist-in-charge,

National Institute of Oceanography, Regional Centre, Cochin for encouragement and facilities provided in carrying out this work. Thanks are also due to the officers and crew of *R.V. Gaveshani* for the help rendered in collecting the samples.

MATERIAL AND METHODS

During the cruise 227 of *R.V. Gaveshani* from March 16 to April 2, 1992, 46 plankton samples of both surface (0-10m) and vertical (0-200m) were collected from 27 stations of five traverses off the Kerala coast (Fig. 1). Heron-Tranter net (mouth area 0.25m² and 150 µm mesh size) was used for collections which were preserved in buffered formalin and later stained with rose bengal for separation of living planktonic Foraminifera in the laboratory. For quantitative study a Rigosha flow meter was fixed to the net.

This study employed a multivariate statistical approach with a factor analysis as described earlier (Jayalakshmy and Rao, 1991).

Also, 27 samples of surface (0-10m) and 19 samples of vertical (0-200m) tows were

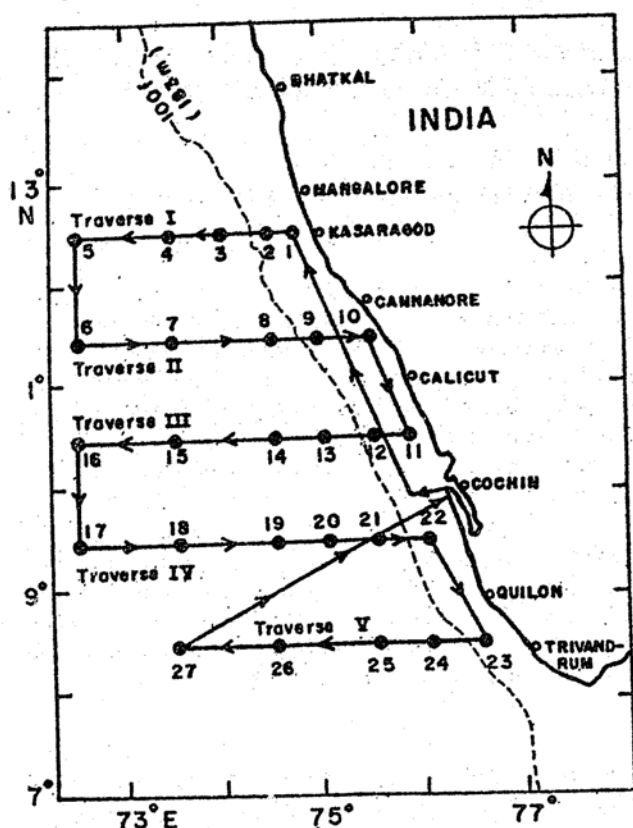


FIG. 1 Map showing sampling sites

clustered by the single linkage group method as outlined by Sanders (1978).

HYDROGRAPHY

During February to October/November, the coastal surface currents are set towards the south and are reversed during remainder of the year. A detailed study of hydrography of southeastern Arabian Sea during summer season has been previously reported (Ramasastry, 1959; Jayaraman *et al.* 1960). The temperature distributions indicate the presence of a more or less isothermal water down to 50 meters. In the surface layer, the temperature increases until when a maximum close to 31°C is observed. The thermocline forms at about 80m depth. Surface salinities in summer show variation from $33.5-35.5 \times 10^{-3}$. In this period, the prevailing winds being northerly to north-easterly, which due to Ekman effect

transport the surface-waters offshore, thereby initiating a weak upwelling from below off the south-west coast of India. According to Sharma (1966), upwelling in these waters starts from February and prevails till July/August. This is confirmed by him by the upward tilting of the thermocline towards the coast from February onwards. During northeast monsoon season (December-April), Düing (1967) also noted slow upwelling along the coast.

Hydrographic observations, in this study, are confined to the measurements of temperature and salinity of the surface-waters (Fig. 2A, B). In these waters, surface temperature varies from 28.7° to 30°C and there is a decrease in gradient of temperature from south to north-west region and lower temperatures are observed in the northern part. The spatial variation of salinity is from $34.5-35.0 \times 10^{-3}$. Higher salinities of the waters are recorded in the area, north of Cochin. During summer (March-May), there is no large-scale upwelling along the coast.

RESULTS AND DISCUSSION

Foraminiferal abundance

In surface tows (0-10m), total concentration of planktonic Foraminifera varies from 941 to 144285, while in vertical tows (0-200m) from 1035 to 10350 specimens in 1000m^3 . Fig. 2C shows that faunal abundance of 0-10m tows increases from south-east direction to north-west. It is also seen from Table 1 that average abundance (\bar{X}) as well as coefficient of variation (CV %) in 0-10m tows show an increase from south to north, *i.e.*, distribution is becoming more dispersed with increase in abundance. The same trend prevails in 0-200m tows also (Fig. 2D) and \bar{X} abundance in the north shows a three-fold increase in comparison with that in the south. The CV ranges from 18% in the north to 46.6% at the southern end with a gradual increase from north to south and this implies that with increase in abundance the distribution of planktonic Foraminifera tends to become more consistent.

TABLE 1. Mean (\bar{X}), standard deviation (σ) and coefficient of variation (CV %) of foraminiferal abundance (no. of specimens in 1000 m³) of all the stations in each traverse

Surface hauls (0-10m)			
Traverse No.	\bar{X}	σ	CV %
I (Stations 1-5)	52585	64205.91	122.10
II (Stations 6-10)	115665	111818.85	96.67
III (Stations 11-16)	22833	27235.78	119.30
IV (Stations 17-22)	33882	25398.99	74.96
V (Stations 23-27)	15659	11489.95	73.38
Vertical hauls (0-200m)			
Traverse No.	\bar{X}	σ	CV %
I (Stations 3-5)	7916	1406.68	17.77
II (Stations 6-8)	7796	3561.37	45.68
III (Stations 13-16)	2580	1404.56	54.44
IV (Stations 17-21)	2262	1054.25	46.60
V (Stations 24-27)	2619	1053.10	40.22

Species composition

A total of twentyeight species belonging to 4 families and 13 genera have been identified and studied quantitatively from plankton

samples of southeastern Arabian Sea off the Kerala coast located between 8° and 13°N and 72° 30' and 77°E. The fauna is dominated by species belonging to tropical and subtropical zones of the world oceans. The dominant species contributing to the bulk of the fauna are : *Globigerinoides ruber*, *G. sacculifer* and *Globorotalia tumida* and the less dominant forms being *Globigerinella aequilateralis*, *Globorotaloides hexagona*, *Globoquadrina conglomerata* and *Globigerinita glutinata*. The remaining species occur in low concentrations. Very rare species ($\leq 1\%$) occurring in this study include *Globigerina falconensis*, *Hastigerinopsis digitiformans* and *Beella digitata*. Species such as *Pulleniatina obliquiloculata*, *Globorotalia menardii*, *G. tumida* and *Neogloboquadrina dutertrei* that dwell in subsurface waters in low-latitude areas with a shallow thermocline are also encountered in the southeastern Arabian Sea, which is thermally well stratified in summer.

In addition, all the species restricted to Indo-Pacific region are observed in waters of

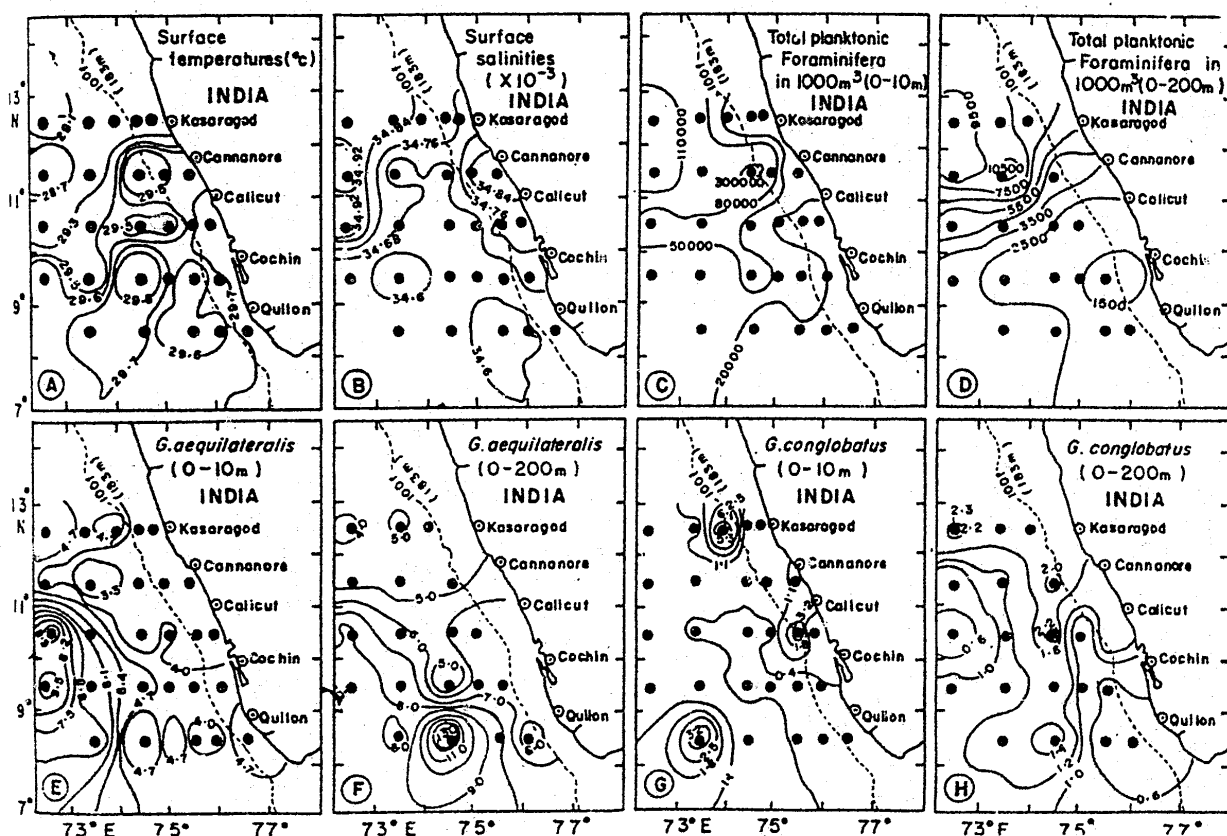


FIG. 2. Surface temperatures (A), surface salinities (B) and total number of specimens in 1000m³ of water in 0-10m (C) and 0-200m (D) tows. Relative abundance (percentage) of foraminiferal species [*G. aequilateralis* in 0-10m (E) and 0-200m (F) tows and *G. conglobatus* in 0-10m (G) and 0-200m (H) tows]

the south-west Indian area, they being in the order of abundance *G. conglomerata* (8.8%), *G. hexagona* (7.4%), *Globorotalia theyeri* (0.4%), *Globigerinella adamsi* (0.2%) and *Globorotalia neoflexuosa* (0.2%). But in the area of central Indian Ocean (between 10° and 13°S and 74° and 76°E) studied earlier in summer, only two species - *G. conglomerata* (0.2%) and *G. hexagona* (0.4%) are found in the plankton samples (Rao, 1992). Based on this comparative study in regard to spatial patterns of the abundance and distribution of these Indo-Pacific species in Indian Ocean, it is found that they generally seem to be very rare south of equator.

Distribution patterns based on relative abundance of dominant summer species and also of forms which are rare in this season are as follows:

(1) *Globigerinella aequilateralis* (Brady) - This species in 0-10m tows shows density of 9.5% of the total population in the middle area

of western part of the Arabian Sea, which is nearly twice in concentration in comparison with other areas (Fig. 2E). In 0-200m tows, the species shows an increase in gradient of density from north to south, the abundance becoming almost double in the southern area (Fig. 2F).

(2) *Globigerinoides conglobatus* (Brady) - It is a summer species showing higher concentrations in 0-10m than in 0-200m tows. In 0-10m tows, it ranges in abundance from 0.4 to 6.1% with higher densities in the northeastern and southwestern areas of the study area (Fig. 2G). Its abundance in 0-200m tows is very low with variation from 0.6 to 2.3% showing relatively higher concentrations in the northern area (Fig. 2H).

(3) *Globigerinoides ruber* d'Orbigny - This summer species in 0-10m tows shows a steadily increasing trend in abundance from north to south and higher abundances are observed in the southwestern area (Fig. 3A). In 0-200m

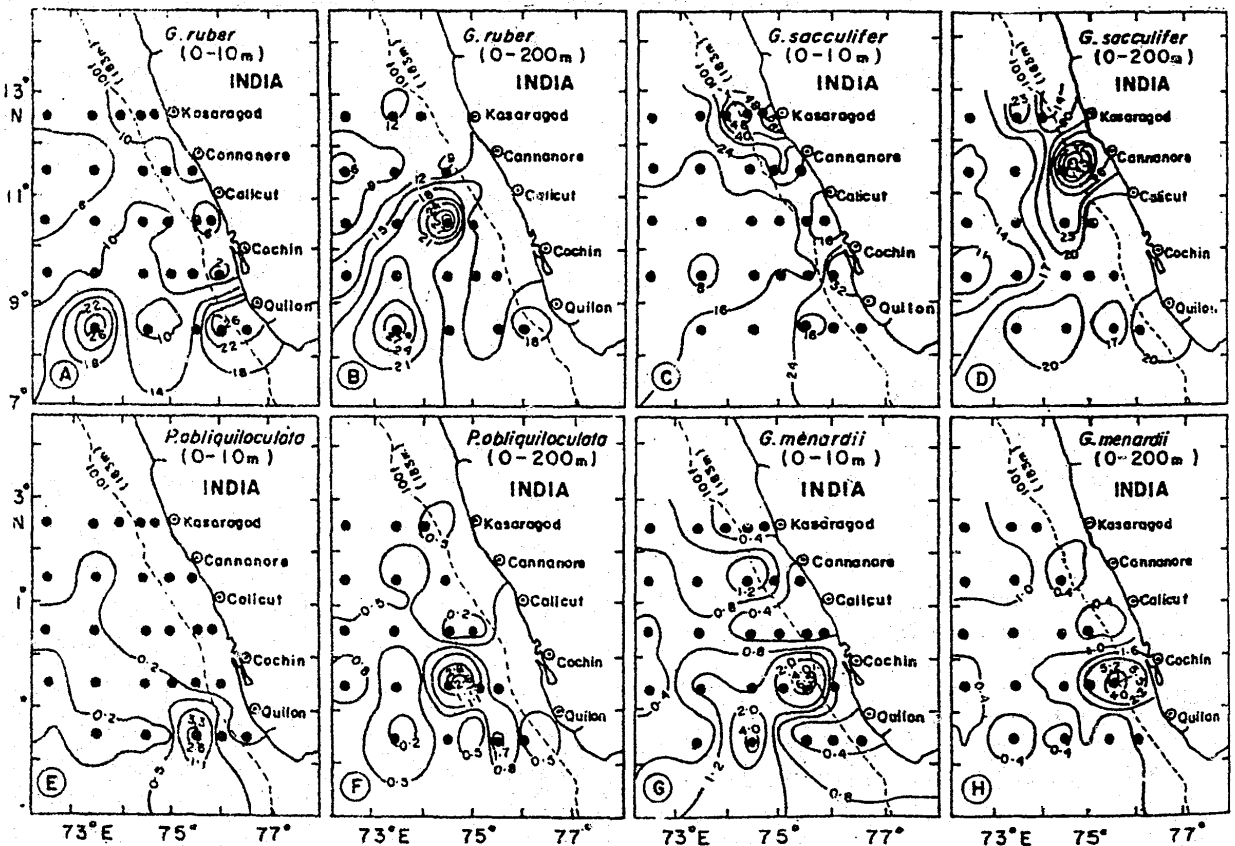


FIG. 3 Relative abundance (percentage) of foraminiferal species [*G. ruber* in 0-10m (A) and 0-200m (B) tows, *G. sacculifer* in 0-10m (C) and 0-200m (D) tows, *P. obliquiloculata* in 0-10m (E) and 0-200m (F) tows and *G. menardii* in 0-10m (G) and 0-200m (H) tows].

tows, with a solitary exception at st. 14 where it shows concentration of 32.8%, the same distributional trend of surface tows is observed in abundance (Fig. 3B).

(4) *Globigerinoides sacculifer* (Brady) - This is a predominant summer species showing higher concentrations in 0-10m tows in the eastern part, especially at the northeastern area of Arabian Sea (Fig. 3C). The same distributional pattern in abundance of this species prevails in 0-200m tows also (Fig. 3D).

(5) *Pulleniatina obliquiloculata* (Parker and Jones) - It is rare in summer season showing variation in abundance from 0.2 to 3.3% in 0-10m tows south of Cannanore

(Fig. 3E), while in 0-200m tows, its density varies from 0.2 to 2.8% with relatively higher concentrations in the southern area in particular off Cochin (Fig. 3F).

(6) *Globorotalia menardii* (d'Orbigny) - This tropical and subtropical species shows density variation from 0.4 to 6.5% in 0-10m tows with higher concentrations near Cochin area (Fig. 3G), while in 0-200m tows, similar distribution of this species is observed with density varying from 0.4 to 5.5% (Fig. 3H).

(7) *Globorotalia tumida* (Brady) - It is the most abundant species observed in the fauna with a gradual increase from south to north in

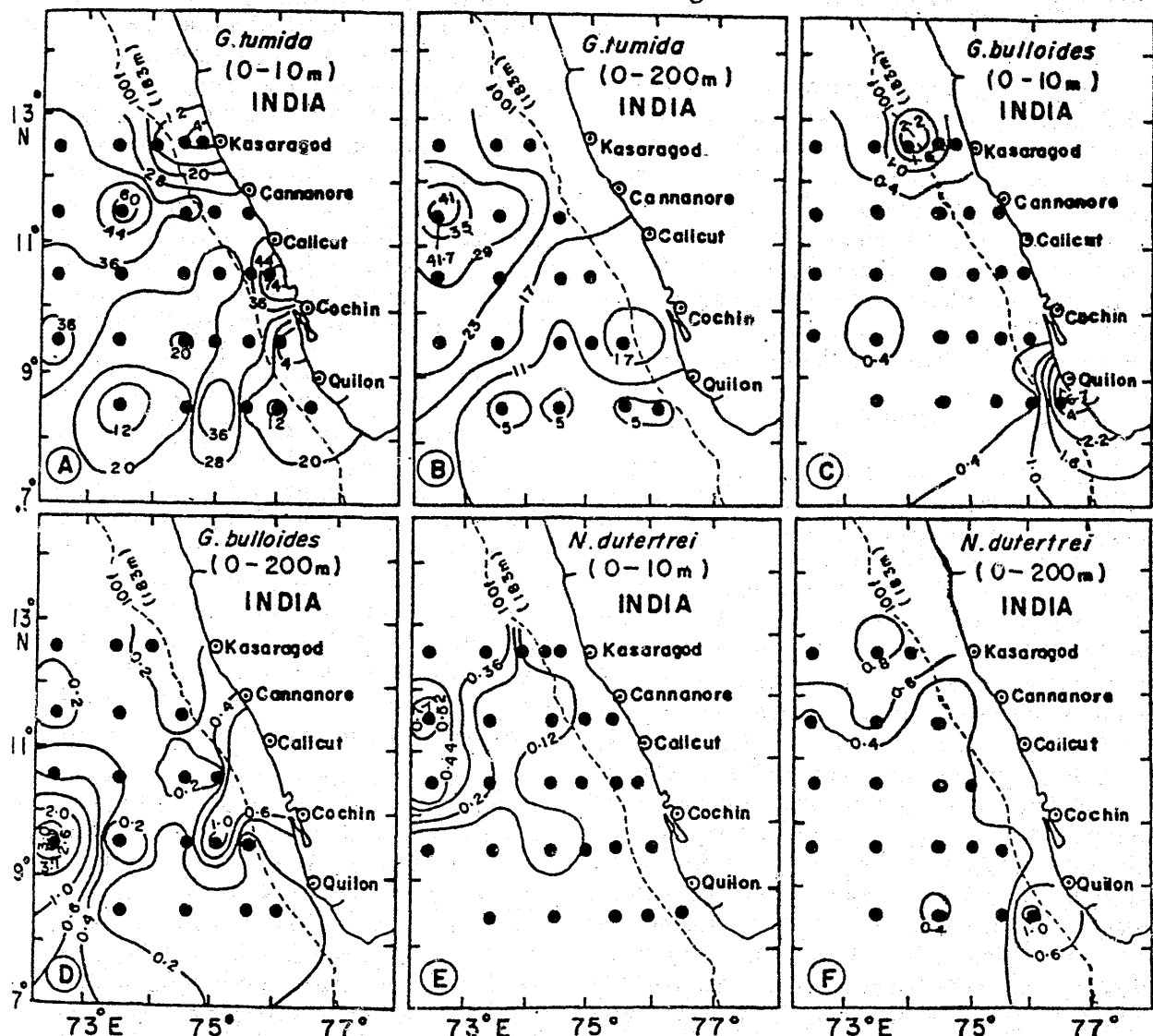


FIG. 4 Relative abundance (percentage) of foraminiferal species [*G. tumida* in 0-10m (A) and 0-200m (B) tows, *G. bulloides* in 0-10m (C) and 0-200m (D) tows and *N. dutertrei* in 0-10m (E) and 0-200m (F) tows]

0-10m tows and higher abundances are observed in the north-west area of the Arabian Sea (Fig. 4A). In 0-200m tows, its density shows variation from 5 to 41.7% and distribution pattern is same as shown in 0-10m tows (Fig. 4B).

(8) *Globigerina bulloides* d'Orbigny -

Presence of this species is an indication of upwelling process which is slow along the coast. In plankton tows, it varies from 0.4 to 6.7% (0-10m) and from 0.2 to 3.1% (0-200m) of the total population. Relatively higher concentrations of this species are observed in nearshore waters of Quilon for 0-10m (Fig. 4C) and in offshore waters of Cochin for 0-200m tows (Fig. 4D).

(9) *Neogloboguadrina dutertrei*

(d'Orbigny) - It is known to be a productivity-cum-upwelling indicator species. Its relative abundance in 0-10m tows increases from south to north towards north-west area ranging in concentration from 0.12 to 0.7% of the total population (Fig. 4E). In 0-200m tows, it occurs in south-east and north-west areas of Arabian Sea with density variation from 0.4 to 0.8% of the total population (Fig. 4F).

Comparison with other regions in north Atlantic

The areas covered during summer season with which comparison of faunal data can be made are: (i) northern Sargasso Sea (Bé, 1960) and Tolderlund and Bé, 1971), (ii) western north Atlantic (Cifelli, 1962) and (iii) north Atlantic (Bé and Hamlin, 1967). The present study is similar to that of the western Sargasso Sea and the western north Atlantic in that the fauna is characterized by summer species such as *G. ruber*, *G. sacculifer*, *G. conglobatus*, *G. aequilateralis*, *O. universa* and *H. pelagica*, but differs from that of the aforementioned regions in showing *G. sacculifer* as the most abundant species in lieu of *G. ruber*. In the case of *G. ruber*, although white tests occur along with pink tests in the north Atlantic, the latter are found to be very abundant only in the western part and sparse in other areas of the ocean. Furthermore, the number of pink tests is higher in summer as this variety prefers warm conditions of the waters, but rare or absent during

other seasons. Only the white variety occurs in Indian Ocean and the pink variety is restricted to the areas in tropical-subtropical Atlantic Ocean (Cullen and Prell, 1984).

A multivariate study: a factor analysis of foraminiferal distribution

A factor analysis method has been used for analysis of data of planktonic foraminiferal biocoenoses in samples collected off the Kerala coast. From Q-mode factor analysis of 26 foraminiferal species of surface tows (0-10m), eight factor groups have been derived (Table 2A) with row normalisation and varimax rotation based on their relative abundance, all of which are statistically significant ($\lambda \geq 1$) explaining about 78.3% of variability in species distribution. Of these factor groups 1, 6, 7 and 8 have negative factor loadings and all others have positive factor loadings. This grouping suggests that in each group only highly coexisting species, for example, *G. sacculifer* and *G. ruber* are clustered together. It is proved also from distributional studies of modern planktonic Foraminifera elsewhere that *G. sacculifer* and *G. ruber* always coexist, even though the latter is a subtropical species.

On the other hand, the factor analysis carried out for grouping of 28 species collected from vertical tows, has grouped them into nine factor groups, of which six (Table 2B) are statistically significant ($\lambda \geq 1$) and could explain about 83.3% of the changes in the species distribution patterns. Further, individual factor group explained variability ranges between 4.0 and 28.8%. Maximum variability is explained by the factor group 1, which has higher range in relative abundance of the species concerned and contains both rare and dominant species.

R-mode analysis applied to group the stations for surface tows using column normalisation and varimax rotation resulted in four factor groups (Table 3A). All groups have negative factor loadings. It is seen from this table that traverse V is not categorized by any factor group suggesting it may be a distinct one having the lowest foraminiferal abundance (Table 1) in comparison with other traverses. Remaining traverses distributed partially or completely in one or the other of the four

TABLE 2. Factor analysis (Q-mode) for the foraminiferal species of surface (A) and vertical (B) tows

(A)					
Factor number	Species	Range of maximum factor loading	Eigen value	Closeness ratio	Variance explained (%)
I	1,10-12	-0.6582 to -0.8198	7.58	29.15	20.29
II	13,16,18	0.8142 to 0.9529	2.68	3.48	10.61
III	17,25	0.7839, 0.8770	2.48	49.01	12.02
IV	5,14	0.9445, 0.9790	2.02	56.77	8.34
V	4,9	0.7142, 0.9122	1.62	63.00	8.68
VI	2,20	-0.8341, -0.8738	1.41	68.42	8.43
VII	7,22,23	-0.6075 to -0.9018	1.29	73.37	11.39
VIII	26	-0.5832	1.26	78.25	6.01

Legend: [*G. bulloides* (1), *G. calida* (2), *G. falconensis* (3), *G. rubescens* (4), *G. adamsi* (5), *G. aequilateralis* (6), *H. parapelagica* (7), *H. pelagica* (8), *G. tenellus* (9), *G. conglobatus* (10), *G. ruber* (11), *G. sacculifer* (12), *O. universa* (13), *P. obliquiloculata* (14), *G. flexuosa* (15), *G. hirsuta* (16), *G. neoflexuosa* (17), *G. menardii* (18), *G. scitula* (19), *G. theyeri* (20), *G. tumida* (21), *G. ungulata* (22), *G. hexagona* (23), *G. conglomerata* (24), *N. dutertrei* (25) and *G. glutinata* (26).]

(B)					
Factor number	Species	Range of maximum factor loading	Eigen value	Closeness ratio	Variance explained (%)
I	2,4,6,8,9 11-14,22,23 25-28	-0.4579 to -0.9072	12.47	44.54	28.75
II	7,21,24	-0.4837 to -0.9907	3.66	57.61	15.39
III	3,17	0.7626, 0.9694	2.43	66.27	7.62
IV	5,20	-0.8223, -0.8911	2.07	73.66	7.30
V	1	0.9180	1.51	79.06	6.33
VI	16	-0.5950	1.19	83.33	4.03

Legend: [*G. bulloides* (1), *G. calida* (2), *G. falconensis* (3), *G. rubescens* (4), *G. adamsi* (5), *G. aequilateralis* (6), *H. digitiformans* (7), *H. parapelagica* (8), *H. pelagica* (9), *B. digitata* (10), *G. tenellus* (11), *G. conglobatus* (12), *G. ruber* (13), *G. sacculifer* (14), *O. universa* (15), *P. obliquiloculata* (16), *G. flexuosa* (17), *G. hirsuta* (18), *G. neoflexuosa* (19), *G. menardii* (20), *G. scitula* (21), *G. theyeri* (22), *G. tumida* (23), *G. ungulata* (24), *G. hexagona* (25), *G. conglomerata* (26), *N. dutertrei* (27) and *G. glutinata* (28).]

factor groups with the same sign for the factor loadings perhaps explain prevalence of same environmental conditions contributing to the foraminiferal abundance.

tows (Table 1). Plot of the factor loadings of the first two factors for the species of surface tows (Fig. 5B) gives rise to three assemblages of which two are the first two factor groups

TABLE 3. Factor analysis (R-mode) for the stations of surface (A) and vertical (B) tows

(A)					
Factor number	Stations	Range of maximum factor loading	Eigen value	Closeness ratio	Variance explained (%)
I	4-8,10-12, 14,15,17,21	-0.6580 to -0.9652	17.62	65.25	37.52
II	1,3	-0.9414, -0.9821	4.79	82.99	22.29
III	16,18-20	-0.7979 to -0.9009	1.79	89.62	19.51
IV	2,13	-0.7750, -0.9320	1.57	95.43	13.77
(B)					
I	4,13-15, 19,24-27	-0.5154 to -0.9521	14.45	76.24	35.44
II	3,5-8, 16,21	0.5660 to 0.9540	2.22	87.70	31.13
III	17,18,20	0.6900 to 0.7973	0.95	92.66	21.70

The same factor analysis carried out for stations of vertical tows produced three significant groups ($\lambda \geq 1$), which explain about 98.3% of the variability in the distribution of stations (Table 3B). This grouping of stations shows that traverses III and V are similar and so also traverses I and II in regard to faunal abundance while traverse IV is different from other traverses in having the least faunal abundance (Table 1).

From the plot of factor loadings of the first two factors for stations of surface tows, the assemblages marked (Fig. 5A) are same as significant factor groups given in Table 3A. In the case of vertical tows also, the assemblages of stations (Fig. 5C) obtained are similar to those given in Table 3B. The difference lying between these two plots is that in the case of surface tows, the stations plotted are more scattered than those of vertical tows, *i.e.*, the faunal distribution is less homogeneous in surface tows compared to that of the vertical

given in Table 2A, while the third one includes factor groups 3 to 7. In this plot, species are more closely placed indicating high coexistence between species. Similar plot for vertical tows shows four assemblages (Fig. 5D), which are the first four factor groups as given in Table 2B and species in various assemblages are found to be more scattered than those of surface tows, indicating less coexistence between species for vertical tows ($r > 0.60$) as compared to surface tows ($r > 0.65$). Factor score distributions of species/stations of surface and vertical tows when examined revealed positively/negatively skewed distributions which are significant ($z > 0.77$), thereby indicating a continuously varying population for each species from station to station and at each station from species to species.

It is also observed from cluster analysis for the species/stations based on relative abundance as examined by dendrograms in which species/stations form groups (indicating

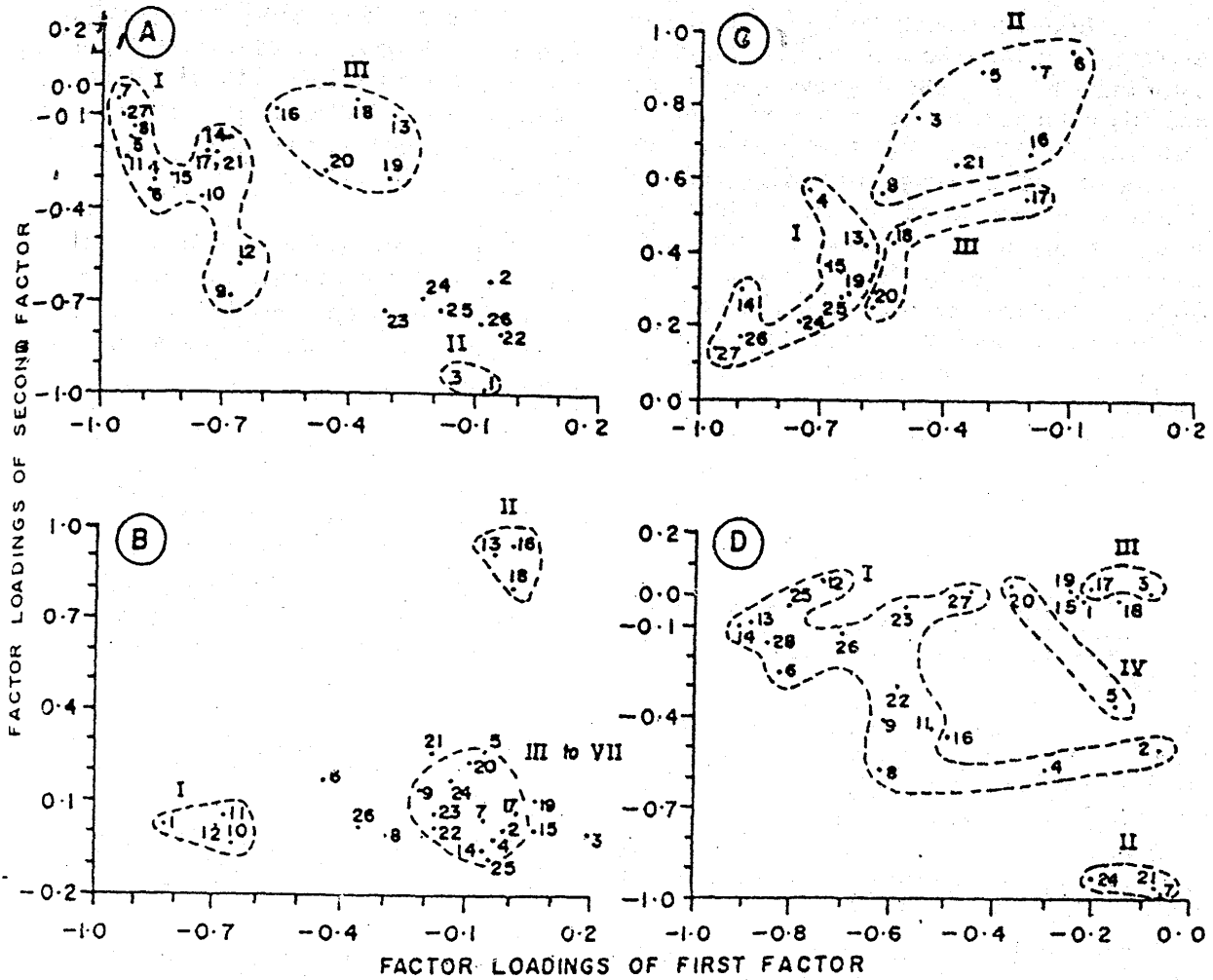


FIG. 5 Plot of the factor loadings of first two factors showing distribution of stations (A) and species (B) for 0-10m tows. Plot of the factor loadings of first two factors showing distribution of stations (C) and species (D) for 0-200m tows. The assemblages are marked.

coexistence at correlation levels, $r > 0.65$ for species, $r > 0.90$ for stations in surface tows; $r > 0.60$ for species and $r > 0.85$ for stations in vertical tows) which are almost same as the assemblages of species/stations in each of the factor groups for surface and vertical tows respectively.

CONCLUSIONS

1. Twentyeight species of planktonic Foraminifera have been identified from 27 samples of 0-10m and 19 samples of 0-200m plankton tows. In general, spinose species of the genus *Globigerinoides* are the most dominant, while species of the genera like *Globigerina*, *Pulleniatina* and *Neogloboquadrina* are rare.

2. The mean of foraminiferal abundance of stations in different traverses along the coast shows that it increases from south to north.

3. Presence of two distinct faunal assemblages: (i) summer tropical and (ii) summer tropical upwelling assemblages has been confirmed. The former assemblage is characterized by species such as *G. aequilateralis*, *G. conglobatus*, *G. ruber* and *G. sacculifer*, while the latter one consists of *G. bulloides* and *N. dutertrei*.

4. Upwelling indicator species - *G. bulloides* and *N. dutertrei* have been observed in low frequencies along the coast and their abundance presupposes a region of weak upwelling during summer.

5. Multivariate study with a factor analysis of planktonic foraminiferal distribution in the coast indicates grouping of species into (i) rare and (ii) dominant, besides a few rare ones in different factor groups by Q-mode analysis for species of both surface and vertical tows and it reveals as well in an accentuated form that factor groups of these plankton tows which have the same sign for factor loadings contain highly coexisting species. Also, this grouping of species suggests that dominant forms are adaptable to a great range of environmental features.

The same study with R-mode analysis for stations in 5 traverses of the plankton tows has provided a tangible proof that traverses 5 (0-10m) and 4 (0-200m) are distinct in that they have shown the least foraminiferal abundance.

6. The fauna, as well as showing a striking similarity with that of certain areas in the north Atlantic, could amply testify to the summer hydrographic conditions as prevailing in the Arabian Sea.

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